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A correlation study of continuously monitored gamma dose rate and meteorological conditions

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ABSTRACT

In this paper, the correlations between the continuously monitored gamma dose rate (GDR) and meteorological parameters, including precipitation, air temperature, relative humidity, air pressure, wind direction, and wind speed, were analyzed by using one year of the hourly dataset from a monitoring system with ten stations. The correlation coefficients are varied by the range of each meteorological parameter. Precipitation would enhance the GDR up to 84%, which is highly related to precipitation intensity and ground type. Strong and positive correlation between the GDR and light precipitation was identified, while the correlation was reduced with increasing of precipitation. Air temperature could cause a fluctuation of the average GDR within the range 1.8–5.3 nGy h^{-1}, and different correlation characteristics were indicated for low and high air temperature. The GDR was positively correlated with relative humidity, though relative humidity is inversely correlated with air temperature. Correlations between the GDR and air pressure were mainly negative. Diurnal variations between the GDR and the air temperature, relative humidity, and air pressure were also analyzed. The wind played an important role also in the fluctuation of the GDR with the GDR difference up to 2.00 nGy h^{-1} averaged from the sixteen wind-directions. Lower GDR can be found in the direction of prevailing wind because of the dilution effect of the radon progenies in the surface air. In this paper, some exploratory interpretation of physical influence mechanisms of meteorological parameters on the GDR was also presented, which suggests further work should be carried out to explore the variation and correlation principle.

1. Introduction

Nowadays, thousands of gamma dose rate (GDR) monitoring stations have been established across the world. The national and international monitoring networks or exchange platforms are constructed progressively (Hiemstra et al., 2009; Szegvary et al., 2007a). Typical monitoring platforms include the EURDEP system in Europe and RadNet in the US (De Cort and De Vries, 1997; De Vries et al., 2005; Fraass, 2015). The systems are constructed mainly for early warning in a radiological emergency after the Chernobyl accident in 1986 (Bossew et al., 2017; De Vries et al., 2005; Szegvary et al., 2007a). After the Fukushima accident in 2011, various monitoring networks are improved, in respect of monitoring devices, and data communication and exchange technology (Brunes, 2017; Huang et al., 2014; Ji et al., 2017; Urso et al., 2012).

In China, there are 149 national GDR monitoring stations (Radiation monitoring technical center of Ministry of Environmental Protection (China), 2017), and regulations of the environmental radiation around the nuclear power plant (NPP) are strengthened by both local government and the nuclear power enterprise (Huang et al., 2014). The purpose is also an early warning of nuclear accidents, but during the normal operation of NPP the generated data are just collected and limited to the detection of the anthropogenic radioactivity. However, detailed research with the long-term monitoring of the GDR could help us to understand the fluctuation mechanism with scientific significance, and also to estimate the possible abnormal or accidental release more accurately (Bossew et al., 2017; Szegvary et al., 2007b).

The GDR in the surface air is mainly originated from the U and Th series and ^{40}K in the ground and the secondary cosmic rays (SCR) (Beck et al., 1972; Bossew et al., 2017). The GDR fluctuation is usually expected from radon and its progenies in the surface air (Wissmann, 2006), which is affected predominantly by meteorological conditions. Precipitation is the most significant factor, as it can enhance possibly by hundreds of nGy h^{-1} of the GDR owing to scavenging of short-lived

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radon progenies, mostly ^{214}Pb and ^{214}Bi (Bossew et al., 2017). The corresponding peak is generally known as the radon peak or the rain peak. Because of the strong effect of precipitation, the correlations between the GDR and other meteorological parameters were rarely reported in the past years.

Variations in radon concentration with meteorological conditions are the basic reason for the GDR fluctuation. It has been reported that the GDR can be used as a proxy or predictor of terrestrial radon flux because the strong correlation between radon concentration in the atmosphere and the ambient GDR was usually observed (Chan et al., 2010; Szegvary et al., 2007b; Tchorz-Trzeciakiewicz and Solecki, 2018).

Besides, air pressure also causes GDR fluctuation due to the attenuation of gamma radiation or SCR, and the component is primarily a function of the local air pressure (Domborwski and Wissmann, 2008; Wissmann et al., 2007).

In this paper, the correlation study between the GDR and the typical meteorological parameters, including precipitation, air temperature, relative humidity, air pressure, wind direction and wind speed, was based on the hourly dataset over one year from a networked monitoring system with ten stations in China. This correlation study may give some insight into the physical fluctuation mechanism of ambient GDR. It may also be helpful to better establish a baseline for each station so as to identify the abnormal release from NPPs.

2. Methods

2.1. The site environment and meteorological conditions

The study area is located in the southeast of China, facing the East Sea (Fig. 1). The monitoring stations are mainly located along the coastline, facing the sea or off the coastline at certain distances. On the north and northwest side, there is hilly land with a maximum altitude of about 100 m. The vegetation coverage rate is high and no high radiation background area exists in the area.

According to decades of data from the national meteorological monitoring station around the site, the average air temperature in the area is registered as about 18.7 °C, and the extreme temperature is −5.2 °C and 40.6 °C. The average relative humidity is approximately 78%, and the average air pressure (barometric pressure) is 1010 hPa with a diurnal variation waveform with two peaks and two troughs. The relative sunshine duration in this area is approximately 40%. The average annual precipitation is approximately 1740 mm, mainly from April to September with the amount of 70%. The yearly prevailing wind-directions are from NNW to N, NE to NNE, and S, corresponding to the land wind, coastal wind, and sea wind, respectively.

The local tide is a typical semidiurnal tide with an extreme range of about 7 m.

2.2. Description of the monitoring system

Ten stations were constructed around Ningde NPP in different directions and distances, mainly within about 10 km (Fig. 1). Continuous monitoring of GDR and seven meteorological parameters, including precipitation, air temperature, relative humidity, air pressure, wind direction, wind speed, and dew-point temperature, is carried out at each station.

In the monitoring system, five stations are installed on the ground near the coast, typically surrounded by vegetation, and the others are installed on the roofs of buildings with concrete surfaces at a relatively far distance from the coast (Table 1). We denote the ground station as G and the roof station as R. Among the stations, station z1 and z7 are housed in an integrated metal container with a height of 2 m, and the monitoring devices are installed on the top. Station z9 is located on a sloping field on an isolated island. Station z2 is located on the coast with the largest depression angle among the stations, and the GDR is expected to be influenced more significantly by the tide because the gamma radiation from the near tidal zone would be shielded by the seawater at high tide.

In each station, a high-pressure ionization chamber, RSS 131 ER, from GE Energy is used. The monitor is widely used in China because of its high-performance with respect to G-M probe. The monitoring range covers from a low level to $1\ Sv\ h^{-1}$ with a sensitivity lower than $2.6\ \mu A\ Gy^{-1}\ h$, and the typical accuracy is below 5% under the condition of $100\ nGy\ h^{-1}$. The relative energy response related to the gamma-ray 661 keV of ^{137}Cs can be kept within 15% in the range of 70 keV to 8 MeV. The temperature effect was corrected automatically for each monitor through the persistent storage of the correction factor before it leaves the factory. It can be ensured to remove the temperature impacts in the range of −25–55 °C. The chambers are installed in glass-fiber-reinforced plastic shelters about 1 m from ground or roof level and are kept away from tall buildings and trees as far as possible.

Tipping-bucket-type meters with a resolution of 0.1 mm were used to monitor precipitation. The monitors of air temperature, relative humidity, and air pressure were installed on a meteorological rod at a height of 1.5 m from the ground or the roof level, with the accuracies of 0.1 °C, 3%, and $0.1\ hPa\ ^{\circ}C^{-1}$, respectively., The monitors of the wind speed and wind direction were installed on the same rod 10 m above the ground or roof level with the accuracy of less than 2%.

All monitors are equipped with a uniform power supply at each station and operated with quality assurance through routine calibration and inspection. The data are saved in a local control computer in minutes and sent to the data center in real time through redundant communication methods of the public wireless network and the fiber-optic network. The hourly data are averaged in real time through the software in the data center.

Besides on the monitoring system, some meteorological parameters can be monitored from the local meteorological observatory with a 100-m tower at the NPP site (Fig. 1). At different observatory height, various meteorological parameters are measured. In this study, to reduce the effect of ground disturbance from the wind field, data of wind direction and wind speed at the height of 80 m were used, rather than that from the monitoring station at the height of 10 m. The precipitation data were also adopted from the meteorological observatory due to the failure of several precipitation meters in the monitoring stations. In fact, limit differences of precipitation were observed by comparing the effective data from the stations to that from the observatory.

2.3. The monitoring data

In this study, acquisition rates of the hourly dataset for the GDR and different meteorological parameters are nearly 100% over the whole year 2016. To reveal the correlations between the GDR and the air temperature, relative humidity, air pressure and wind field, the data when precipitation occurred were left aside to eliminate the disturbance of precipitation. To study the fluctuation characteristics, we defined a fluctuation factor, $\delta\gamma$, which is equal to the normalized GDR minus one. The normalized GDR was determined by dividing each value by the annual average.

It should be noted that the GDR contributed from anthropogenic sources of global and Chernobyl fallout is considered unimportant (Barescut et al., 2011; Bossew et al., 2001). Besides, there was no abnormal emission from the NPP in 2016. So, the GDR could be ascribed to the natural contribution.

The contribution from the possible influence of the NPP release in normal operation could be estimated roughly as follows.

Four CPR 1000 nuclear power units (China Pressurized Reactor) operated on the site. The main gaseous source term is ^{133}Xe for the reactors. From effluent monitoring experience, the typical radioactivity concentrations are below 1000 $Bq\ m^{-3}$ as the minimum detection concentration (MDC). By adopting the emission rate of the gaseous effluent about 100 $m^3\ s^{-1}$ and the maximum atmospheric dispersion